LaFarm Greenhouse

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INTRODUCTION

LaFarm is a sustainability initiative at Lafayette College with the mission to integrate curriculum and practice in sustainable food and agriculture for the campus community. LaFarm grows produce for the dining halls, recycles nutrients from composted food back to the soil, and serves as a laboratory for collaborative student-faculty education and research. Our hope is that LaFarm will continue to engage students across all disciplines and facilitate the necessary conversations about sustainability, agriculture, and business.

Currently, LaFarm does not have a greenhouse and has rented greenhouse space from the Seed Farm in Emmaus, PA. We believe that implementing a greenhouse at LaFarm would promote its educational opportunities, increase agricultural yield, and ultimately benefit the local community in a sustainable way. This Capstone Project presents a feasibility study on alternative designs for a sustainable greenhouse to be implemented at LaFarm. After considering the various social, policy, technical, and economic contexts of LaFarm and the community, we provide a proposal for the scope, scale, and impact of three different types of greenhouses.

Research Question: What would it take to get a greenhouse at LaFarm that would be sustainable and would best fulfill the current needs of LaFarm?

Research Goal: Analyze three standard greenhouse designs for how they would change LaFarm and expand educational opportunities at Lafayette College, and define the processes for constructing them sustainably within that system.

LAFARM HISTORY

"LaFarm" is the acronym used to describe the "Lafayette College Student Working Farm and Community Garden". It is a two-acre working farm and community garden located about 3 miles from Lafayette College's main campus. LaFarm is positioned between Lafayette's off-campus athletics center, Metzgar Field, and several acres of arable land that are owned by Lafayette but leased to a local farmer.

In 2009, a student named Jenn Bell started LaFarm, under the guidance of Professor Art Kney and help from fellow students. Bell received a grant from the Clinton Global Initiative University Conference known as the CGI-U Outstanding Commitment Award, which funded the initial purchase and construction of LaFarm's fence, shed, basic equipment, and the first year of seeds. Jenn managed the farm until 2012, when the project received additional grant funding to establish a Garden Manager position, which has been held by Sarah Edmonds. In addition to Sarah's management, an advisory board for the farm was established to oversee the project. The current members of the LaFarm Advisory Board are Professor Cohen, Professor Brandes, Professor Lawrence, and Professor Germanoski.

Under this new management structure, LaFarm has grown to produce a multitude of organic, heirloom varieties of vegetables such as tomatoes, squash, peppers, sweet corn, potatoes, kale, broccoli, and cauliflower. Additionally, the farm has expanded to engage participation from members of the local community with a desire for agriculture but without the means to maintain their own crops. About two-thirds of LaFarm's land serves as the student-working farm, which provides produce to the dining halls and composts food waste from the dining halls back into nutrients for the farm. The remaining portion of LaFarm is dedicated as an organic community garden for members of the local community in Easton and Forks Township.

THE PHYSICAL AND SOCIAL ECOLOGY OF LAFARM

The USDA breaks up the United States into specified agricultural zones defined by regions with similar climates in terms of average sun exposure, rainfall, temperature, and frost dates. LaFarm, Lafayette College, and Easton, PA are all located in USDA Zone 6, a semi-arid climate. The USDA Zones clarify what types of crops grow in that region and what steps should be taken in order to grow non-native plants. For example, tomatoes are not native to Pennsylvania, yet many farmers grow tomatoes here. The USDA suggests that tomato plants in Zone 6 should be started indoors to grow properly, as they cannot withstand the cool temperatures common to this region.

A farm's soil is very important to its operations. The amount of organic matter in the soil indicates the kinds of biological micronutrients available for plants, which influences how various plants will grow in that soil. Likewise, soil quality dictates which cultivation methods are most effective (e.g. more clay soils are harder to till by hand, drip irrigation is difficult in sandy soils, etc.) LaFarm has a rocky, clay-based soil with about 2% organic matter. Prior to being in organic production, the soil was mostly inert as it was under conventional GMO corn and soy cultivation.

LaFarm's current technological infrastructure includes: a small gazebo, which provides a shady respite for laborers, 2 equipment sheds, and a sanitary drip irrigation system powered by a solar-powered pump. The land in production is surrounded by a deer fence and there is a 50 ft barrier between this fence and a conventional farmer's land to prevent cross-contamination.

The principal reason for using greenhouse space is for seed starting, which is a vital aspect of growing most vegetables in USDA Zone 6. Seeds germinate in highly fertile soil inside the greenhouse. Plant growth is facilitated and controlled by the heat and other beneficial conditions provided by the greenhouse. After the weather warms to the point where the plant could survive outdoors, the partially grown plant (called a transplant, noun) is taken and transplanted (verb) into the soil of the farm. Without starting seed or buying transplants, the type and amount of produce a farmer can grow in Zone 6 is very limited. LaFarm doesn't have a greenhouse and therefore rents greenhouse space from The Seed Farm in Emmaus, Pennsylvania, located more than an hour's commute from campus. The greenhouse utilized by LaFarm is neither easily accessible nor sustainable (due to the 45 minute drive both ways).

LaFarm has expanded to be more than just a bounded space. LaFarm is now the cornerstone of Lafayette's Sustainable Food Loop, a system of students growing food for consumption by students on campus, composting the remains, and using that compost to produce more food. Above all, LaFarm's overarching goal is to serve as an educational laboratory for research, participation, and discussion among students and faculty. Multiple classes, such as Professor Cohen's Technology & Nature class, have used the farm to educate, and many students have done research with professors on topics like Integrated Pest Management, Small Farm Infrastructure, while working on projects such as the Vegetables in the Community project. In addition, working on the farm has given many students valuable training in sustainable agriculture, from the outdoor skills to the know-how to plan and manage as well as how to run a market and sell wholesale. Not only has this helped train future food producers, but the LaFarm initiative is also creating a body of information accessible to small farmers in the Lehigh Valley.

OUR PROJECT

LaFarm is a keystone for biodiversity and agricultural research at Lafayette, it strives to be a model for small farmers around the Lehigh Valley for best practices and meeting industry standards, and it is a functioning garden for members of the Lafayette community. Implementing a sustainable greenhouse at LaFarm would provide a space for interdisciplinary research and education on agriculture and food in fields from chemistry and biology to anthropology and economics. It would also create more comprehensive education about sustainable vegetable production in USDA Zone 6 and would further develop a model that could be emulated by local producers.

The reason behind analyzing three alternative greenhouse designs is that LaFarm has hopes of expanding in coming years. There is the potential for LaFarm to not only expand in size in various directions, but also expand in scope. Lafayette could reclaim more of the land it is currently renting out, and create an environmental campus as an extension of the main campus, similar to the space at the base of College Hill that is becoming an arts campus. As there are so many different layers to LaFarm, we agree that no one can be sure what exact changes will occur at LaFarm over the next few years. We thus offer three possible designs for a greenhouse that can fit into the possible trajectories of LaFarm in the coming years. This research foundation will lay out a practical path to the best greenhouse for LaFarm's needs.

The first type is a small-scale greenhouse with no mechanical or electrical inputs, commonly known as a hoophouse. The second type is a medium-scale, Gothic Framed Greenhouse, which is larger in size, incorporates basic mechanical and electrical systems for ventilation and heating, and therefore would provide seed starting capabilities at LaFarm. The third design is a large-scale, state-of-the-art, A-Frame Greenhouse. This would be a permanent structure with fully automated ventilation and heating systems. This structure would be permanent and, though costly, the A-frame greenhouse would offer great educational and production opportunities. Integral to all of these designs is that they are as environmentally sustainable as possible, so the adaptations to normal designs in order to make these sustainable are included in the following analyses.

While it is outside of the scope of this project to construct any of these designs due to limited time and resources, we aim to fully define the reasons for having any of the above designs at LaFarm, as well as what would be required to fully realize these designs. This project will hopefully serve as a guide for other members of the Lafayette community in order to improve LaFarm's educational and productive capacity.

To navigate this website, either use the dropdown menu under LaFarm Greenhouse or follow the links below. We recommend following the links in the order presented to get the full picture of this project; the Social Context expands upon the introduction above, each Analysis section examines our greenhouse solutions from a new lens, and the Conclusion provides a summary before our proposal of how our analyses can inform future decision making.

SOCIAL CONTEXT

The Lafayette Student Working Farm and Community Garden, abbreviated LaFarm, serves several purposes. Firstly, LaFarm serves as a community garden space for students, staff, alumni, and faculty. More importantly, however, is the student working farm portion of LaFarm, which provides space for students to grow food under the direction of LaFarm Manager Sarah Edmonds which can be donated or sold directly to members of the Easton and Lafayette community or to dining services for wholesale use.

There are many stakeholders involved in LaFarm. There is LaFarm Manager Edmonds, the LaFarm Advisory Board (currently professors Cohen, Lawrence, Germanoski and Brandes) and of course the many students that volunteer with or work for Manager Edmonds, do research at LaFarm, and take part in the Lafayette Food and Farm Cooperative (a student organization for agriculture inclined students). There's the community gardeners, from their diverse backgrounds, and the Plant Operations Staff that help Manager Edmonds. And there are also Alumni interested in the farm, most notably Mr. Hendrickson, who has a fund set up for projects that combine engineering and art. This fund has been crucial in the past for paying for the solar powered irrigation well at LaFarm, and means that implementation of any project at LaFarm should take art into account.

For this project, the most crucial aspect of LaFarm is its educational capacity as it is used by these students. Assessing our greenhouse decision through the lens of educational context will allow us to choose a type of greenhouse that aligns with LaFarm's practices, ideals, and future while still considering environmental and infrastructural contexts.

Education, The Sustainable Food Loop, and Community Engagement

LaFarm is a part of the larger Lafayette community, and, as such, education is paramount. LaFarm strives to provide a space where not only students, but also faculty and small farmers from around the Lehigh Valley can learn about small-scale agriculture. For students, this often takes place through faculty-student research projects. This has included a diverse breadth of classes including Independent Studies, the Civil Engineering Capstone Design, Technology and Nature, Environmental Engineering, Hydrology, Introduction to the Environment: A Systems Approach, Organizations and the Environment, and Edible Ethics. There have also been Excel Research Projects covering topics like Integrated Pest Management, Community Outreach and Small Farm Infrastructure that have taken place through LaFarm with tremendous contributions from Manager Edmonds. In addition, many Lafayette students learn experientially by working or volunteering under Manager Edmonds, and draw value from LaFarm by contributing service hours. Service has been popular for fraternity members on campus, especially Delta Upsilon, as well as for service days like the Green Apple Day of Service and Earth Day.

Operating under strict industry standards, LaFarm strives to be a model place for small farmers to glean important knowledge about agriculture such as how to grow, what to grow, when to start and when to harvest. However, seed starting and season extension are critical parts of agriculture in our region that necessitate a greenhouse, which LaFarm does not have. A greenhouse would enable LaFarm to educate small farmers and students on how to perform these tasks and construct their own greenhouses, and potentially provide space for local farmers or other community members to use alongside Lafayette. For example, there is a senior center which was recently relocating to a space across the street from LaFarm, and members of the senior center expressed interest in being able to work with plants at LaFarm. Although there is not an opportunity for the seniors to help right now, a large greenhouse could easily contain space for such outreach.

A greenhouse would also be an educational boon to faculty-student excel researchers seeking to expand their focus at LaFarm, because of the large number of research projects which could be done with greenhouses. Projects that can be done in greenhouses range from altering the heat and ventilation to increase efficiency, investigating how to make the perfect greenhouse growing media, working with hydroponics or aquaculture, the study of the biology of the plants themselves as well as investigations into biomass heating and the sequester of CO2 for plant use (for a few examples of academic research on greenhouses, see: Beshada, Zhang, & Boris, 2006; Sanchz-Molina, Reinoso, Acien, Rodriguez, & Lopext, 2014; Sethi & Sharma, 2008; and van der Velde, Voogt, & Pickhardt, 2008).

LaFarm currently utilizes space at a greenhouse at the Seed Farm in Emmaus, PA. The 45 minute commute both ways is severely inhibiting both institutional and community educational opportunities. Furthermore, changeover in the administration of the Seed Farm has led to complications which may mean that that space is not even accessible to LaFarm in the future. In this context, inaccessibility is the hurdle we would overcome with a LaFarm greenhouse.

Additionally, the emissions from the drive reduce the overall sustainability of LaFarm. As part of Lafayette's Sustainable Food Loop infrastructure (LaFarm -> Dining Services -> Food Waste Composting -> LaFarm…), LaFarm is held to a higher standard. A presentation that was given about the Sustainable Food Loop at the LVAIC 2014 Sustainability Conference is located here: LaFarm Sustainable Food Loop Presentation. Bringing a greenhouse to LaFarm would further improve the Sustainable Food Loop both in the production capacity and in its overall sustainability.

Environmental Context
On a grander scale, LaFarm's educational and infrastructural context involves the world outside the Lafayette and Lehigh Valley communities. LaFarm is part of a small farm movement in America. Growing concerns over emissions related to large-scale farming production have compelled many individuals and groups to maintain their own land, share land in farm co-ops, or undertake any number of activities to produce their own food. This enables people to break out of the large farm and grocery store's unsustainable food infrastructure and establish their own food loops which are more sustainable. By passing on knowledge and know-how for small agriculture to students past and present, faculty, and local farmers, LaFarm serves a greater purpose in furthering this movment.

The environmental context that applies to this project influences our greenhouse design greatly. Our location falls under USDA Zone 6 which expects a certain amount of snowfall and rain each year. This means a greenhouse here will have specifications to prevent collapse from snow buildup. This will be covered further in our technological section. In addition, the outside climate that our greenhouse will be exposed to play a huge role in helping us determine what types of heating systems we will need. We are taking into account the immediate environment of LaFarm in that the greenhouse cannot be placed in a floodplain or in an area that is either too sunny or too shady.

Furthermore, we must think about how a greenhouse would affect our environment as a whole. With this, the question arises; would it contribute significantly to global warming? Ideally, LaFarm would have a net zero greenhouse. But, with limited solar power accessibility, as discussed in the Technical Analysis section, how to power a greenhouse becomes complicated. To avoid this problem, it is possible to expand the sustainable energy infrastructure at LaFarm in order to power a greenhouse. Ascertaining the exact amount of infrastructure necessary is itself an opportunity for further environmental education and research by Lafayette.

Looking Ahead

Another important factor to consider is the potential expansion of LaFarm. Lafayette owns over 12 acres of land adjacent to LaFarm which is currently rented out to a local GMO farmer. There is a lot of student and faculty desire to reclaim that land and put it to educational use. As of 2015, there has been talk of allowing LaFarm to expand an additional acre from where it is, but also talk about reclaiming land on the other side of the property, adjacent to the Bushkill Creek. Furthermore, the professors of the LaFarm Advisory Board have expressed interest of using the whole of the land that Lafayette owns adjacent to Metzgar as an environmental campus. There is great potential for education there between LaFarm and the creek's uses for engineering, geology, environmental sciences; there is the potential for housing in the house on that land, and the current and future sustainable energy infrastructure in place at LaFarm and Metzgar gives even more opportunity for education and sustainable living.

But none of these plans have been finalized or approved, in the short term or long term. Since it is impossible to know at this time exactly where LaFarm will be next year or in ten years, our analysis has resulted in a set of suggestions rather than a strict plan. These suggestions are predicated on the facts that LaFarm is educationally focused, that it is expanding at an uncertain rate, and that it can become the cornerstone of an entire environmental campus. Taking into account this, the rest of the context on this page, and everything in the introduction, we set out in the following sections to analyze three greenhouse designs which involve different technical aspects and implementation strategies, and would affect the contexts we have described in various ways. We have selected three designs which make sense based on these contexts: a hoophouse which could be easily implemented and help expand interest and production at LaFarm; a Gothic-Frame greenhouse which would take more work to implement but allow us to safely start seed and eliminate any need for off-farm greenhouses; and an A-Frame greenhouse which would be top of the line, achieve more than the Gothic-Frame, and allow additional education and community engagement. Each of these designs is explored in detail in the technical analysis.

For more information about the context of the Lehigh Valley, as well as an overall history of agriculture in the US, please see Resetting the Table in the Lehigh Valley, *a book written by Lafayette students in 2014, cited in the bibliography. For more information about LaFarm itself see both the LaFarm Annual Reports, also linked in the bibliography.*

Technical Analysis

Greenhouses have been in use for hundreds of years, and particularly in America, industrial standards have arisen. The express purpose of a greenhouse is to create a space that can be kept hotter than outdoors while still being open to sunlight. This is achieved through a structure made of translucent materials, originally glass but now mostly plastics, which will help keep light in and keep cold out (Coleman, 2009). As with any technology, there are problems in this system. The two primary problems became that as greenhouses got bigger, without ventilation pests and diseases become unmanageable and that modern agriculture demands more heat in greenhouses than is possible without added heating.

	Hoophouse	Gothic Greenhouse	A-Frame Greenhouse
Frame	Gothic Frame	Gothic Frame	A-Frame
Size	30×48	30×96	30×96
Side Material	Single Layer Polyethelyne, maximum light penetration	Double Layer Polyethelyne, keeps in more heat	Polycarbonate, durable, permanent
Location	Over good soil for growing, among rows	Close to the field, but not on it, hopefully accessible by road	Close to field, not on it, accessible by road
Ventilation	End Wall Passive Ventilation	Powered Ventilation system, roll up sides, ridgevent	Powered Ventilation system, ridgevent
Heating	Nothing added	Electric Blankets	Forced Air, electric blankets
Energy	None	Blankets, Ventilation	Heating, Ventilation
Use Potential	Extending in ground season by providing heat over certain rows	Space for starting seeds in the beginning of the season and for growing in ground at the end	Place for starting seeds, growing in pots, hydroponics, etc.
Durability	Single layer poly needs to be replaced on average every 3 years	Double Layer Poly needs to be replaced on average every 5-7 years	Polycarbonate on average needs to be replaced after about 10 years, can be replaced piece by piece
Extra Equipment	None	Benches/tables	Benches/tables, pots, hydroponics infrastructure in the future
Notes	–	–	On a concrete foundation, a permanent structure. Would require shades and shade control
Maintenance	Polyethylene checked for tears when it is used, little/no special training required	Ventilation and heating mats need to be checked daily, training required in how to operate and understand these systems	Ventilation and heating systems need to be checked daily, training required in how to operate and understand these systems

So over time expensive and fragile glass greenhouses were replaced with cheaper designs using acrylics, and then polycarbonate when acrylic was deemed to vulnerable to fire. Even cheaper, more temporary greenhouses made of simple frames and polyethylene sheets proliferated, for creating spaces that could support varying levels of micro-climate control. Passive ventilation was supplemented with large, powered ventilation units, and new passive ventilation technologies like ridgevents and roll-up sides were invented. And supplemental heat in the form of radiators, electric heating mats, and forced air systems are now used to create spaces in cold climates which can support growing produce originally intended for warm climates, either by starting the seeds to be moved outside later or by growing the plants entirely indoors.

These new standard designs require a good deal of energy, and have a good deal of variation, but that variability follows a formula. That formula takes into account the shape, size, material, and location of the greenhouse as well as how it is ventilated and heated. These different aspects of the design impact how much energy the greenhouse requires, how it can be used, how durable it is, what other equipment will be necessary, how much it will cost and how it needs to be maintained. Below, we provide a table summary of these different parts of each design, a detailed explanation of each aspect, and then an analysis of each design. The issue of cost is explored in depth in the Economic Analysis.

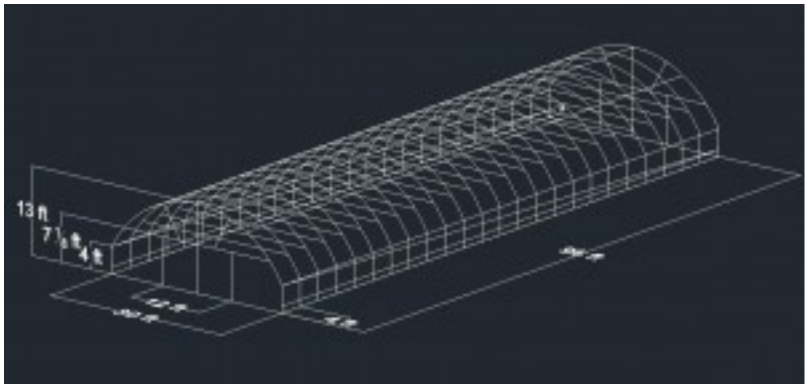
OVERVIEW

Explanation

This section draws on information gathered through personal interactions with LaFarm Manager Sarah Edmonds, Bud Peltz from Griffin Greenhouse Supply, and USDA Agent Tianna DuPont. (For more information and additional support see Cohen, 2014; Coleman, 1989; Coleman, 2009; Kuria & Titus, 2012; Ponce et al., 2015; and Upson, 2014).

Frame Shape. The overall shape of a greenhouse can be described as having 2 end walls and a tubular section between them. The shape of the frame is the shape of the tube.

Gothic Framed Passive Ventialtion Greenhouse (size of our hoophouse design)



Dimensions of the Gothic Frame Greenhouse


An A-Frame Greenhouse (Shape and scale of our High-Tech Greenhouse)

The Gothic Frame shape is necessary for polyethylene greenhouses in USDA Zone 6 because the Gothic frame sheds snow, and can therefore stand up to the snow load in our climate. The A-Frame allows for more moving and growing room, and is better for a permanent structure which will be able to stand up to the snow regardless. Additionally, to make the A-Frame greenhouse design permanent, it would have to go on a concrete foundation like a normal building, unlike the other designs which would just go on the ground.

Size. The floor size of the greenhouse. 30×96 is the largest standard size, allowing for the most room. For greenhouses without a powered ventilation system, the length can be no longer than 3 times the width (depending on wind patterns in the climate of the location) or wind will not pass through, which would cause problems with pests and diseases. Therefore we would limit the hoophouse size to 30×48, which is the largest standard size which can reliably be ventilated passively.

Side Material. For cheap/temporary greenhouses, polyethylene is the standard material because it blocks little light and traps a lot of heat, while being inexpensive. A single layer of poly will block little light but keep in less heat than double layer poly, which naturally does block out more sun. Double layer also has an envelope of air between the layers which keeps in more heat, and lasts longer. In USDA zone 6, the trade off between heat and sunlight filtration in going from a single layer to a double layer is worthwhile, because more heat is more important than more sunlight. Still, in order to inflate the air envelope, powered ventilation is necessary.

For permanent greenhouses, there are more options for wall material. The classic is glass, but glass is so expensive to construct and repair that despite its advantages, most companies will not even build glass greenhouses any more. The most used materials now are acrylic and polycarbonate. Acrylic is more expensive and lasts longer, but is not fire safe, making it a dangerous option. Polycarbonate will not last as long, but is as sturdy as acrylic, keeps in about as much heat and sun, is cheaper and does not burn. Additionally, permanent greenhouse materials generally keep in heat significantly better than polyethylene.

Ventilation. Ventilation is required in greenhouses to get pests out, to regulate temperatures, and to prevent buildup of disease. In order for the greenhouse to be controlled enough to risk starting seeds to grow into transplants, when plants are especially vulnerable to pests and disease, powered ventilation is necessary. This powered ventilation takes the form of large fan units which force air through the entire greenhouse, and sometimes additional fans in the middle of the greenhouse to move more air.
For temporary greenhouses, which are not used during the winter, roll up sides are generally used to allow for extra ventilation A) during the hottest months and B) during the winter, to allow the weather to sterilize the soil. These involve a mechanism for rolling up the polyethylene sides.

Methods of passive ventilation increase control of the temperature as well. Ridge vents are mechanisms for opening a ridge along the length of the greenhouse which creates a type of heat flow which will not instantly cool down soil (the most important part to have hot) but allows for heat to leave the greenhouse.

Heating. Extra heating in the greenhouse allows the greenhouse to be used even further out of season. This is extremely useful for starting seeds. Despite that, most greenhouses usually have some form of radiator to heat them which is wasteful, and heats the greenhouse uniformly, burning fuel. For a greenhouse that is being used to start seed, a less wasteful option for heating is the use of heating mats which can be set to an individual temperature for each bench, allowing for the best temperature for germination for each type of seed. These do use more electricity than a forced-air system, but do not use fuel, and can be used individually and maintained separately.

Since the permanent greenhouse can potentially be used for things like vertical growing, winter growing, keeping potted trees in during the winter, or other long term projects of the like, having a forced-air system that can allow for climate control may become necessary. This raises the question of fuel. There is the possibility of installing a geothermal heating unit, but this would While there are some designs of forced air systems where air or water is heated by the sun and circulate through the greenhouse, designing a truly sustainable heating system for a permanent greenhouse beyond the electric blankets would be an entire project in itself.

Energy Requirements. The addition of powered ventilation units, heating mats, and forced air heating systems would require power for these systems. On an average day, using the ventilation system and heating mats of either the Gothic or A-Frame Designs could easily require around 90kWh of power. Using the forced air system instead of the mats would require closer to 60kWh, but a forced air heating system would require additional fuel for heating which, as mentioned above, would require a whole research study into being sustainable. Currently, the solar array at Metzgar with 16 panes on 2 panels, generates at most 16kWh a day on sunny days (during the fall), and on especially cloudy days generates closer to 1kWh. This means in order to be sustainably powered, we would need some 90 panes on 12 solar panels, batteries for storing the energy, and hopefully wind turbines to continue power generation on cloudier days. (Based on data gathered from https://www.mypvpower.com/dashboard/750 and calculations done based on the electrical requirements of the greenhouses, detailed in the quotes given to us by Griffin Greenhouse Supply) (Peltz, 2014a; Peltz, 2014b). A Microsoft Excel spreadsheet which shows our calculations is located here: Calculating Energy Requirements for Greenhouses.

The Electrical Systems for the Gothic Greenhouse are 4 Wadsworth Vent Motors, 2 Exhaust Fan Motors, and 48 20″ by 48″ electric heating matts. The Electrical Systems for the A-Frame Greenhouse are 4 Wadsworth Vent Motors, 2 Exhaust Fan Motors, 2 sets of Motorized Shutters, and 2 Modine Heating Units and/or the same 48 electric heating matts.

Durability. The different siding materials have different levels of vulnerability. A single layer of polyethylene is vulnerable to damage like hail and wind storms, and is hard to repair (the damage is generally ignored until it is severe enough to be replaced.) Under normal conditions, polyethylene needs to be replaced every 3 years because of damage. For reasons including extra durability due to the air envelope and a higher threshold of damage to actually interfere with the operations of the greenhouse, double layered polyethylene needs to be replaced on average after 5-7 years, depending on the amount of damage. Replacing the double layer poly is a more complicated process than the single as well.

Polycarbonate is a sturdy material and fares much better against storm-related and everyday damage. On average, polycarbonate will last around 10 years. Additionally, since polycarbonate greenhouses are made up of panes of polycarbonate, individual panes can be replaced as needed, which can disperse cost over time. Polycarbonate is now the standard for permanent greenhouses because of how fragile and expensive glass is, and because it is cheaper than, and does not catch fire like acrylic siding does.

Use Potential. Because of the limitations of heat and ventilation, as outlined in their respective sections, the hoophouse's use would be limited to growing plants in the ground. Transplants in a hoophouse can be put in when it would be too cold outside, and plants living in a greenhouse can last longer into the season because they can survive past the outside frost dates, which offers potential increase in growing potential. Furthermore, research can be done in the hoophouse to analyze how these plants interact with the unique microclimate created in the hoophouse.

The Gothic greenhouse can be used for starting seed because of the added ventilation. This means being able to teach students how to start their own seed, cutting out costs of buying transplants and/or transportation to and from an offsite greenhouse for starting seed. Starting seed would require “greenhouse benches” which are essentially screen tables that are designed so that they will not hold disease or create space for pests. Additionally, in the Fall, when seed starting is done, this greenhouse can be used for anything the hoophouse could, and more effectively due to the extra ventilation.

Because of the permanence and the amount of control over the microclimate of the A-Frame design, not only can it be used for starting seeds more effectively than the Gothic design, in the future it can also be the site for experimentation with hydroponics or vertical gardening, it can be used for growing plants in the winter, and plants like citrus trees can be grown in large pots and moved between the greenhouse and outdoors depending on the season. Additionally, the extra climate control makes experimentation with chemistry, heat flow, biology, and soil science much higher.

ANALYSIS

Hoophouse. The hoophouse design is an extremely simple physical structure: several sets of metal pipes and wooden end-walls with a polyethylene covering. Industry standard versions of this design can be ordered from multiple sources such as Nolt’s Produce Supplies, and can be constructed by Garden Manager Sarah Edmonds and a few workers or volunteers in a single day. It would be placed in a location where LaFarm could grow food in the ground: away from the southeast corner of the farm which is prone to flooding, either over some of the rows that are currently used for growing or in a space outside the current fence where the soil is healthy if LaFarm expands. Then the hoophouse will be used by Sarah to grow earlier in the season, with vegetables like tomatoes or fennel, and potentially later into the season with crops like spinach. It would not require constant maintenance and therefore would *not* require someone to watch it every day, but after it became majorly damaged it would require a new polyethylene sheet, probably around once every 3 years.

It would also not be a place that could be used to start seeds, it would only be able to extend the season of in ground plants, increasing production and altering when things could be harvested. It could also be a space for experimentation, especially around the topic of how much extra production can result from such a design.

Gothic Greenhouse. The Gothic greenhouse is a standard design that is indispensable for most vegetable growers. The frame and end walls are the same as for the hoophouse, but this design would be twice as long and it would have two layers of polyethylene with an inflated envelope of air between to keep in more heat. Double layered polyethylene is more durable than single layered and would not need to be replaced nearly as often (on average, 5-7 years of life.) It would have a ridge vent, roll-up sides, and large ventilation units which would keep pests and disease out better than it would be possible to with a passive design, which would make it safe enough for starting seeds. This requires benches and heat. The heat will be delivered by heating blankets because these can be powered by electricity alone (meaning they could be powered by solar panels and wind turbines without a fuel source.)

To supply this energy sustainably, there would need to be many more solar panels out at LaFarm (potentially over 5 times more,) and hopefully more wind turbines, but there would be no fuel requirement. This system could potentially be constructed by LaFarm workers, but is more likely to be constructed by a contractor. Installing additional solar panels and wind turbines would also require contracting. Furthermore, the heating and ventilation systems would need to be checked daily for failure, meaning that there would have to be training done for someone to take check and maintain the greenhouse daily. This design would be used to start seeds in the Spring and early summer, and could be used to grow in ground during the end of the season. This means it would still need to be located somewhere there is good soil, like the hoophouse. Because it can start seeds, LaFarm would be able to use this space to expand connections with the local community, giving space to local farmers or others wanting to start seed. Additionally, it could be used by students to experiment with biology, chemistry, geology, etc. as it pertained to agriculture.

A-Frame Greenhouse. The A-Frame design is highly advanced, and beyond the industry standard as it is a permanent structure. It would require a concrete foundation and a metal frame, with polycarbonate walls. The polycarbonate panels have an average life of around a decade, but can also be replaced one as a time as needed. It would have powered ventilation just like the Gothic design, as well as a ridge vent (no roll-up sides, as you cannot roll-up polycarbonate.) This would make it safe enough for starting seeds. It would also have a forced-air heating system which could be used if a sustainable fuel source were found, and electric blankets just like the Gothic greenhouse. Because the permanent design keeps in heat much better than either of the temporary ones (which is a great advantage in the cold months,) it is necessary to have shutters which can be controlled by a motor to help regulate the temperature of the greenhouse by blocking the sun when necessary (during the hottest days of summer.) Because these shutters use very little energy, the only major addition of energy between the Gothic design and this one is the forced-air system, which uses less energy than the heating mats which would not be used concurrently. This means that the expansion of energy production infrastructure at LaFarm would be the same for this design as for the Gothic design.

Since this design would allow for even more climate control than the Gothic design, the A-Frame greenhouse also offers extra space for local community to grow inside, and offers much higher potential for students to do scientific research inside. But, because it has a concrete floor it can no longer be used for growing in the ground, and would therefore be better to place in a location with less fertile land. It would also be good to have this design located somewhere with road access (especially if it would be being used for community programs.) The best location for this in reference to LaFarm's current potential land would be near the micro-apiary, near the Metzgar maintenance building, but depending on how LaFarm expands a different location may become the better choice.

These different designs require different processes for funding, construction, and maintenance, which are explored next in the policy analysis.

Policy Analysis

For any project, the laws, regulations, and standard practices surrounding the project shape how the end result will appear. Furthermore, for a technological system, best management practices determine how the technology will be used, and what will be necessary for it to operate effectively. It is this project's goal to lay out the processes by which our greenhouse designs could be realized, and the policies surrounding greenhouses and construction in America, Pennsylvania, and at Lafayette College define those processes. It is in this section that we explore those policies and the explain those processes.

POLICIES REGARDING GREENHOUSES AND CONSTRUCTION

Federal Policy Concerning Greenhouses. The only standards that are enforced by law in the United States about greenhouses refer to what plants can and cannot be bought and sold to other countries. That being said, USDA extension services at universities across the nation have created various Best Management Practices (BMPs) for Greenhouse construction and management which are considered the standard by which to adhere. By reviewing the BMPs laid out by Cornell, University of Massachussetts, Oklahoma State University (multiple pdfs in bibliography,) and Purdue (which has links to the guidesheets produced in many places across the nation), we have become familiar with the many aspects of greenhouse design and management which are recommended. Most of these sources will be integral to the management and growth of any greenhouse at LaFarm in the future, and therefore should be accounted for and reviewed by any who implement a greenhouse plan. Best Management Practices include what materials to use, how to orient and locate a greenhouse, how systems should operate, water quality and distribution, having an integrated pest management plan, fertilization, and weed management (Cox, Bartok, & LaScola 2010; Schnell, Cole & Dole; Schnelle & Dole a; Schnelle & Dole b; Schnelle & Dole c; Tatum & Bonner 2010).

Despite this, federal policy which applies to agriculture more broadly will also affect greenhouses and how they are used. Most significantly the Food Safety Modernization Act will impact all aspects of farming in America. Though LaFarm is exempt from the Act because of our scale (it applies only to farms making above $500,000 of revenue) LaFarm needs to strive to fulfill it not only because the policies laid out ensure the most food safety, but because as an educational farm LaFarm practices all relevant policies to be the best model for illustrating farm work in America. Furthermore, many small farmers are currently upgrading their farms to fit the FSMA even if they are exempt because wholesale buyers and markets have historically been most inclined to seek out sources who conform to standard practices even if they are not legally applicable (Sarah Edmonds, & Tianna Dupont, 2015, personal interaction).

There are several implications of FSMA for greenhouses at LaFarm. Firstly, water quality standards for irrigation and standards for washing produce and sanitizing equipment extend into the greenhouse. More importantly, since adhering to the policy requires upgrades to the washing, packing, and storing infrastructure of the farm but does not require a working greenhouse, projects like the Vegetable Washing Station may need to take precedence over building greenhouses.

Pennsylvania State Policy/Forks Township Policy. One concern for constructing a greenhouse was the question of building permits and zoning. But, in Forks Township (where LaFarm is located), the building codes do not differ from the Pennsylvania Uniform Construction Code, which exempts any agricultural building on agricultural land from building codes. Because LaFarm and all the adjacent land owned by Lafayette is zoned as Recreational/Educational/Municipal (REM) (zoning map, Township of Forks Ordinance 331 Code § 200) it can be used for a variety of purposes including agriculture.

Because the legal regulations for greenhouses and other agricultural construction in Pennsylvania and in the United States more broadly are not very strict, our designs are not very restricted by them. This is undoubtedly the reason for the exemptions of agriculture in Pennsylvania's building code; the exemptions were a step to facilitate the ease of expanding the scale of farming operations and experimentation in a state with a good deal of farmland and a good policy infrastructure for agriculture (with other policies like agriculture conservation easements, lowering the cost of owning land in agricultural production.) This creates a good atmosphere for doing research on such infrastructure, helping our cause.

Lafayette College Policy. Given the precedents of construction at LaFarm of small infrastructures like the two sheds, the apiary, and the Gazebo which was built by the Green Building Club, it would not be hard to say that if the resources for constructing either the temporary hoophouse design or the Gothic greenhouse (which is also temporary as it lacks any foundation and is sided by a plastic sheet) were found, that either of those designs could be constructed by LaFarm Manager Sarah and some LaFarm workers without having to undertake any bureaucratic process. At the same time, since the Gothic design will require some electrical systems it would be advisable to have it constructed professionally if possible.

As for the permanent greenhouse, which would need professional construction equipment, a concrete foundation, and contractors, the construction of it would go through the capital project process of Lafayette College. Details on submitting a proposal for such a project are located here. As a summary, for the permanent greenhouse a division head needs to support the project (for example, the Provost is the head of the Academic Division, the VP of Campus Life is the head of the Campus Life Division,) the project must be proposed through an online form which will be approved from the Division Head and then advanced to a board for consideration by the following October. After this, the request will need to be formalized further and ITS will help estimate ROI, after which the project may be approved and begin the next fiscal year.

Funding for the greenhouse could be secured from several sources. Yearly, the LaFarm Advisory board and LaFarm Manager Edmonds negotiate the budget for LaFarm, in the past some projects have been undertaken by student organizations with funding from student government, and more complicated projects have had money given to them from what is known as the Hendrickson Fund, funding from a specific Alumnus for projects that integrate technology and art.

PROCESSES FOR REALIZING GREENHOUSES AT LAFARM

Student Organizations. Student organizations like the Lafayette Food and Farm Cooperative (LaFFCo) can request funding from student government. This means that it would be possible to buy the hoophouse or even Gothic greenhouse design entirely with student government funding. Since in its first year LaFFCo secured over $2,000 in funding from student government in order to pay for equipment, it would be very easy to get enough for a simple hoophouse. And the precedent for something as expensive as the Gothic greenhouse being funded has been set. Our club crew team, for example, has gotten $60,000 in years past to purchase new boats. That funding would easily cover the Gothic design. Therefore, there is the possibility that the capital project process and even fundraising through alumni would not be necessary for those two projects. Furthermore, organizations like LaFFCo, which already works closely with LaFarm Manager Edmonds, would be able to provide the labor and capital for some maintenance and operation of the greenhouses, especially the hoophouse or Gothic designs. This would mean that the required maintenance for the greenhouses would be partially covered, and it would be easier for Edmonds and Plant Operations to maintain.

The Capital Project Process. For a capital project to be undertaken, it must be endorsed by a division head and approved by several committees. Because of the academic opportunities provided by a greenhouse, the endorsement it would be best to pursue would be that of the Provost. In order to get that endorsement, it is necessary to focus on the educational importance of the greenhouse in applying for the project. In any application, focus should be given to the way that the Gothic and A-Frame greenhouse designs offer a plethora of research opportunities for engineers and scientists, and about how expanding the farm gives more space for students of any discipline to learn more about agriculture. This will squarely secure LaFarm and its activities as part of the academics of the school, centering the purpose of the greenhouse on education. This is very good because as an educational institution, LaFarm should not be pressured to make a profit through its operations, which many college farms are. Since it is difficult for even professional farmers to live off of their farms, demanding that students who are trying to learn run a profitable farm is overly demanding.

To gain further approval and show how a greenhouse is an important part of Lafayette's future, it is important to note that Lafayette is committed to the Sustainable Food Loop, the system through which food is grown at the farm, eaten in the dining halls, composted by Plant Operations, and that compost is returned to the farm to grow more food. The goal of the Sustainable Food Loop is to make Lafayette's food system more closed and sustainable, and to educate students in sustainability. At this point, LaFarm cannot produce nearly enough to feed the entire student body at the dining halls. But a dedication to this loop, and to sustainability in general, supports a greenhouse project, which will allow LaFarm to produce more of the food for the dining halls for more of the year. Additionally, making the greenhouses sustainable through student research is a great opportunity for Lafayette to further its academic goals around sustainability. A greenhouse is a logical step for Lafayette's continuously growing commitment to sustainability; a commitment that has been demonstrated by the start and growth of the farm itself, by the establishment of the Environmental Sciences and Studies program, making sustainability one of Lafayette's three core principles, and the upcoming hiring of a Sustainability Coordinator.

Additionally, to continue with LaFarm's connection to the Hendrickson Fund, it is possible that those who seek to implement the A-Frame or Gothic designs work with the arts department from the beginning of the process to integrate art and technology in the project. The Hendrickson family can be a valuable ally for championing this project as it has been for LaFarm in the past. Professors Nestor Gil and Jim Toya are especially likely to be interested in the project because of their previous work with LaFarm, food, and technology in their art. For details on how much money would be needed for any of these projects under specific circumstances, see the economic analysis.

ECONOMIC ANALYSIS

This section describes the costs and benefits of our greenhouse designs. For information on how to secure money for greenhouses at Lafayette, see the policy analysis.

Constructing a greenhouse involves costs from several sources. Materials need to be bought from suppliers such as Nolt's Produce Supplies or Griffin Greenhouse Supplies. Construction can then either be done by volunteer labor for the hoophouse design or needs to be contracted out. Furthermore, there is the cost of the equipment that goes into the greenhouse after the construction, the cost for any additional energy infrastructure at LaFarm needed to power the greenhouses, and the costs of maintenance/repairs down the road.

At the same time, having a greenhouse on-site will mean a lot of cost savings. The cost of plants, greenhouse rent, and potting soil makes up 15% of LaFarm's Annual budget in 2014, and that number would rise if LaFarm were to mostly purchase transplants. Additionally transport to and from the off-site greenhouse as well as picking up transplants not only costs money but also time, reducing the overall productivity of the farm. The addition of an on-site greenhouse would both increase the amount of produce the farm can make but also decrease the costs we have.

COSTS

Materials Costs.
For consistency, the materials costs were all obtained from quotes from Griffin Greenhouse Supplies. Griffin Greenhouse Supply provides all the materials needed to construct a greenhouse in customized packages. The Quotes for these costs are located in the bibliography.

Hoophouse Materials Cost

Structure	$ 3,472.00
Roof covering	$ 954.52
Endwall Covering	$ 565.78
Total Materials	**$ 4,992.30**

Gothic Greenhouse Materials Cost

Structure	$ 6,138.00
Roof Vent	$ 2,847.00
Roof Covering	$ 1,586.04
Endwall Covering	$ 565.78
Vent Motors	$ 1,990.00
Roll up Sides	$ 1,164.88
Misc	$ 785.50

Total Materials	**$ 15,077.20**
A-Frame Greenhouse Materials Cost*	
Griffin Quote	$ 90,000.00
Cost of Concrete	$ 5,600.00
Total Materials	**$ 95,600.00**

*When getting the quote for the A-Frame Greenhouse, we were not provided with a breakdown for individual costs (though we have a list of the materials). The overall cost was placed at $90,000.00. The concrete is not supplied by Griffin, but would be purchased by the contractor. Calculating the likely cost of concrete involved finding the average cost of concrete to be ~$80.00 per cubic yard.

Construction Cost.
Griffin Greenhouse Supplies, Nolt's, etc. do not construct/install the greenhouses, but do recommend contractors who would. At this time, we have contacted the nearby contractors but have been unable to get a quote, and are currently estimating the cost of construction being **~$5,000-$10,000.** This construction cost would only be necessary for the Gothic greenhouse or the A-Frame greenhouse designs, the hoophouse is simple enough to be constructed by LaFarm Manager Edmonds and several LaFarm workers.

Additional Equipment.
Beyond normal equipment already on the farm, the hoophouse would not need additional equipment for its operation, but the Gothic A-Frame designs would, because seed starting requires greenhouse benches to keep transplants off the ground and easy to work with. In either of them, to have approximately 24 benches which would give us 2 rows of benches, it would cost ~$2400 for industrial standard greenhouse benches from a supplier such as Griffin. For heating mats as laid out in the technical analysis, it would cost ~$3500.

Cost for additional Energy Infrastructure.
To be able to power the Gothic or A-Frame designs with renewables the amount of potential energy generation at LaFarm would need to be more deeply measured to find the necessary balance of wind, solar, and other methods of generation necessary for the 60-90kWh per day for the designs. Given that, with the data from the 16 panels in the Metzgar Solar Array Dashboard, if we were to assume ~1 250-watt solar panel is able to produce an average of 1kWh of energy per day (a generous estimate, based on data from the dashboard on sunny days in Autumn) and assuming a bulk order of such panels would cost ~$200 per panel, then the cost would easily be approximately $9,000-$14,800, for the panels alone.

For a geothermal system for heating the A-Frame Greenhouse, it could cost ~$4,000 dollars for a heating unit and between $8,000 and $10,000 for installation.

Cost for Operations and Maintenance.
For all the designs, weathering of the structure of the greenhouse means that the materials

need to be repaired/replaced after certain intervals. The life of a single polyethylene sheet as in the hoophouse is generally 3 years, the life of a double layer as in the Gothic greenhouse is 5-7 years and the life of polycarbonate as in the A-Frame is a decade or more, and polycarbonate panels can be replaced as needed instead of needing to be replaced all at once. It would cost $1100 to replace the hoophouse cover, $1700 to replace the Gothic covers. For the A-Frame, individual 4'x8′ polycarbonate panels cost around $100. Taking into account the surface area of the greenhouse, this means that it would take a total of $16,000 to replace all of the panels, though these would not likely need to be replaced all at once and are generally warrantied for 10 years. To estimate the yearly cost of repair for each greenhouse, the costs were divided by the average life of each material, assuming for the A-Frame, the cost was estimated to require all of the panels to eventually need to be replaced over 20 years.

	Hoophouse	**Gothic Greenhouse**	**A-Frame Greenhouse**
Cost of Frame and Materials	$5,000	$15,000	$90,000
Construction Cost	–	$5,000	$10,000
Equipment cost	–	$6,000	$6,000
Cost for Extra Energy Infrastructure	–	$12,000	$25,000
Total Estimated Initial Cost	**$5,000**	**$38,000**	**$131,000**
Yearly Repair Cost	$370	$285	$800

BENEFITS

Seed Starting.

While the hoophouse cannot be used to start seed, the main function of both the Gothic greenhouse and the A-Frame greenhouse is to start seed which would reduce a number of costs that LaFarm incurs. In 2014, LaFarm spent around $2,300 on plants, rent for the greenhouse, seeds and potting soil to start seed (Edmonds, 2015). Previously to that, LaFarm's budget did not have enough money for seeds or transplants and LaFarm Manager Edmonds had to donate her own saved seed and transplants. Furthermore, the price of our greenhouse space has been subsidized in the past by $750 because LaFarm Manager Edmonds attended the Seed Farm and volunteers to work there to reduce the price. Without the space we are renting in the greenhouse, which may be lost soon, the cost of plants would significantly increase, because we would have to buy all transplants. But, with an on-site greenhouse, over the course of several years that number could be reduced to potentially zero depending on several choices down the line.

Potting soil can be produced on the farm with combinations of compost and top soil, if the soil is fertile enough. Though LaFarm doesn't necessarily have that capacity right now, a class or an Excel research project could find a good balance for potting mix that would decrease the cost of soil to nothing. If we start all of our seed ourselves then we will not need to pay for transplants and seed costs fluctuate with the amount of seed that we save v the amount of seed that we buy. Because these costs all depend on future choices, improving the LaFarm system, and doing further research, it is not easy to estimate the amount of savings per year. Still, it can be said that regardless of those choices the costs for seed, soil, transplants and rent will be reduced by having the Gothic or A-Frame designs.

In addition, there is the cost that will be saved from having either the Gothic greenhouse or the High-tech greenhouse in transportation. Since the cost of transportation has been externalized to the Garden Manager, that is hard to measure, but having an hour and a half long car trip multiple times per week uses a good deal of gasoline. Furthermore, that amount of time spent away from the farm decreases the amount of work that can be done, decreasing the productivity as well as the educational potential of the farm.

Other Benefits and Conclusion.
The increase in productivity of the farm is also difficult to calculate in monetary terms for several reasons. Firstly, the productivity of the farm is determined by so many variable factors that it is virtually impossible to determine the exact cause of an increase or decrease in yield. A good example of this is the hail storm that occurred in June of 2015 which did an immeasurable amount of damage to the farm (see this blog post as well as this one). Also, the choice of what to grow always decides something about the yield, but something different about the amount of money that the yield will bring in.
Of course the most important reason why it's difficult to predict how much money these changes would bring in is because most of the produce is now donated each year ($4,000 worth of donations v $4,450 of income in 2013 and $8,290 worth of donations v $5,590 of income in 2014) and much of the yield is taken home and eaten by the various student researchers, interns, and employees of LaFarm. Further, since LaFarm does both direct sales at retail pricing and wholesale price sales to the dining hall, the worth of even individual units of produce is variable depending on whom it is sold to. Therefore, not only is a yield increase dependent on factors that are beyond any farmer's direct control, but because of LaFarm's status as an educational farm that gives food to many sources and also sells to multiple sources, there is no guarantee that yield increase will increase real income.

Still, if all other factors (choice of what to grow, freak weather events, labor hours, management practices, etc.) were held constant, the addition of any of these three greenhouses would increase yield, and extend when most produce would be available for harvest. The hoophouse will do this by allowing earlier plantings in the spring and later plantings in the fall, which would increase the yield of whatever crop is grown there, and make it possible to grow crops that LaFarm otherwise could not, like spinach. Since out of season or hard to grow produce costs more, this does mean there would be an increase in potential income (though, as noted above, that food could be donated, taken home, etc.)

The Gothic greenhouse and the A-Frame will offer that same potential, as well as the indirect yield increase of having extra time saved from transportation. Still, these projects are not likely to actually make money in the short run. These projects are not meant to be a financial investment though, as neither LaFarm nor Lafayette are for-profit institutions. Because we are an educational institution, and these structures will be used first and foremost to educate students and the community about agriculture, these structures should be treated like as an expansion to educational space. The educational opportunities and number of research projects that can be done in these spaces far outweigh the economic costs of these structures. These would be projects like measuring exact gains resulting from certain practices, determining potential yield increase through greenhouse use, or finding the environmental effects of certain practices, which would teach students and add invaluable research to the field.

This last point underlies our suggestions laid out in the Conclusion, next.

CONCLUSION

Research Question: What would it take to get a greenhouse at LaFarm that would be sustainable and would best fulfill the current needs of LaFarm?

Research Goal: Analyze three standard greenhouse designs for how they would change LaFarm and enhance educational opportunities at Lafayette College, and define the processes for constructing them sustainably within that system.

Having examined the social context and analyzed the prospects of these three greenhouse designs from a policy, technical, and economic standpoint, and having taken into account the goals of Lafayette College and all applicable stakeholders, we have reached a set of conclusions about what we think the best plan is and how to achieve that. In addition, because we recognize the multiple changes that can occur we have also laid out a general plan for the implementation of any of the three designs. Below, we analyze the advantages of each and summarize the implementation of them, and end with our suggestions.

Hoophouse.

The hoophouse has a low cost of ~$5,000. This amount of money and the labor needed to construct it could be compiled through a student organization like the Lafayette Food and Farm Cooperative (LaFFCo), meaning administrative help would not be necessary. Such a student organization would need only to request money for the greenhouse from Student Government, then order the parts, and work with LaFarm Manager Edmonds to construct it. Since its maintenance would not need training and would not be a daily activity, it is overall an easy project to undertake. As such, the hoophouse could be simply implemented concurrently with another larger scale greenhouse with greater capabilities.

The hoophouse would enable LaFarm to extend several plants' seasons later into the fall and it offers students and faculty the opportunity to conduct research therein. Potential research projects include studying how the microclimate of the hoophouse differs from the outside climate, how different plants are affected being grown inside rather than outside, how soil fertility changes in the hoophouse year after year by various practices like cover cropping or double planting, or what kind of integrated pest management plan works well for the hoophouse. The hoophouse would be operated by Edmonds and the normal LaFarm workers without difficulty and would increase the potential overall yield of LaFarm and stretch the timing that food would be available for the dining halls, students, and donation.

Gothic Greenhouse.

The medium scale, Gothic greenhouse would cost between $25,000 and $35,000, depending on whether construction was contracted out, and to also construct enough energy infrastructure at LaFarm to power it sustainably the cost would rise to ~$50,000. Though this is significantly more costly than the hoophouse, such funding being secured through a student organization is not unprecedented, and it is therefore possible for this greenhouse to be constructed in the same way as the hoophouse. The construction being contracted out might be preferable to make sure the powered systems are placed correctly, but this is ultimately the decision of Manager Edmonds based on whether she feels it would be constructed correctly. Furthermore, it could cost thousands more to install the energy infrastructure necessary to power the greenhouse sustainably. To construct all of this together, with contractors would change the process for implementing the greenhouse would be different, as it would have to go through the Capital Project Process. The Capital Project Process begins with an application for the capital project. The application states why the project should be undertaken by the college, must be endorsed by a Division Head of the college (most likely in our case the Provost), and then be approved, the funding for it is found, and it is scheduled for being built. The reasons for the college to construct this greenhouse are all of the education, community outreach, and food production capacity expanding functions that it offers.

First, and maybe most importantly, it makes starting seeds early possible. Seed starting is one of the most crucial aspects of modern vegetable growing, as it is necessary to grow most vegetables in our climate. It is only possible to start seed in a greenhouse with powered ventilation and added heat, which is the main divergence of Gothic greenhouse from the hoophouse design. LaFarm currently must start seed in rented greenhouse space or buy transplants from a nursery (a professional greenhouse which starts seeds for farmers,) so creating this greenhouse would be bringing this function on-site. This function of our greenhouse would allow farmers to lease space within our greenhouse and simultaneously offer significant educational potential for these local farmers as well as students and faculty conducting research. The research that could be conducted in this greenhouse includes all the potential projects that the hoophouse offers and significantly more. Additional projects include a plethora of engineering projects centered on studying the effects and efficacy of the ventilation and heating systems of the greenhouse, exploring potential alternatives, investigating the material science of the polyethylene sheeting and potential improvements to it, as well as determining and working with the energy infrastructure necessary to power the greenhouse. Additionally, since starting seed usually requires potting mix, research could be done into how to produce suitably fertile soil on-site. These research projects would compliment the greenhouse's function in starting seed and growing some plants in ground in the fall.

Finding funding for this greenhouse can be done in several ways in conjunction. Money can be used from student organizations, academic departments, the LaFarm budget itself, and from Alumni donations like the Hendrickson fund (which would require teaming with arts students to make this project also an art project.) Raising this money, and constructing the energy infrastructure necessary to power this greenhouse sustainably means that the project could take a few years from when it is initiated to come to fruition. Beyond just getting the greenhouse, this design would also require a good pest management plan to make it suitable for starting seed, and the powered systems would need to be checked daily to assure nothing goes wrong. This means a trained employee, likely from Plant Operations, would need to be able to check the equipment, which means that Plant Operations should be involved in the planning for this greenhouse from early on and that training should be done soon after the construction.

A-Frame Greenhouse.
The A-Frame greenhouse design would be a permanent structure costing upwards of

$100,000, as much as $131,000 including extra energy infrastructure, and would require an outside contractor to construct. This means it would require going through the Capital Project Process, as described for the Gothic greenhouse. With the increased cost though, comes a huge increase in the potential of the greenhouse design.

The A-frame option would be as state of the art as possible with automated ventilation, watering and forced-air heating systems. This highly controlled environment would be the best design for research projects. In addition to all the research that could be done in the hoophouse or Gothic greenhouse, the A-Frame offers a huge amount more. The much more controlled design means that science and engineering research done in this greenhouse would be significantly more accurate and in-depth than it could be in the other designs. Beyond that, such a permanent structure means that there is potential for vertical growing, hydroponics, aquaculture, and many other potential projects which could provide a lot of research for individual students as well as classes. Also, seed starting capabilities would be even more secure than the Gothic design. With this design, Lafayette would be able to give back to the community through very rigorous research as well as through renting space to farmers and other growers in the area, and using the space for demonstrations and instruction. It would do this while providing a valuable function in starting seed for LaFarm. While it would not allow for in the ground growing like the other designs, the A-Frame design would provide space for indoor growing through hydroponics, potted trees, or many other methods.

The funding for this greenhouse would have to be found piecemeal from the sources described in the Gothic section, and the energy infrastructure expansion for this design would not actually be any more intense than for the Gothic design, because they would use mostly the same systems (the only added systems for powering the passive roof vent and shades use very little energy compared to the ventilation and heating systems). Additionally, this design would require daily regulation to prevent issues, like the Gothic design. Since the systems are more complicated, it would require more training, but would be similar to the maintenance require for the Gothic design.

As a bastion of higher education, Lafayette College spares no expense for student learning. This hi-tech greenhouse would echo this fact and set the standard for college and university agriculture and ecology programs around the Lehigh Valley.

Recommendation.
Our suggestion is to implement the hoophouse next fall and extend certain crops' seasons. This implementation would ideally foster interest among students and faculty, creating an infrastructure and demand for greenhouse research and learning. This infrastructure would then give LaFarm the necessary momentum to expand its greenhouse program. To be able to power either of the larger designs sustainably, it will be necessary for a more detailed assessment of the potential for energy generation at Metzgar fields, which could take the form of an Excel project, a class capstone, an independent study, or thesis. Since the Gothic greenhouse and A-Frame greenhouse would serve mostly the same functions on the farm, the next part of our suggestion is to begin the capital project approval process for the Gothic or A-frame greenhouses as soon as the source for energy and fuel is secured.

Optimistically, the capital project process for the A-frame would take one year, fundraising would take another year, and construction would take another year. Complications in finding funding, getting the project approved, or finding a way for it to be powered could make this easily a five year long project.

Our goals through this incremental rollout plan are to attract greater and greater levels of interest in greenhouse mechanisms and technology from the student body, faculty, and local farmers over time as well as increase LaFarm's production. That way, the spending on the large-scale greenhouse would be justified by its educational and harvest potentials. Our assumptions for the future of LaFarm include increased space, larger workforce, and greater funding.

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